MECHANICAL AND TRIBOLOGICAL BEHAVIOUR OF COCONUT SHELL CHAR REINFORCED POLYMER COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Mechanical Engineering

By

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Department of Mechanical Engineering

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CERTIFICATE

This is to certify that the thesis entitled "**MECHANICAL AND TRIBOLOGICAL BEHAVIOUR OF COCONUT SHEL CHAR REINFORCED POLYMER COMPOSITES**", submitted by **Mrs. PRANAYAJOSHI CHANDOLE** in partial fulfillment of the requirements for the award of **Master of Technology Degree in Mechanical Engineering** with specialization in "**Machine Design and Analysis**" at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/Institute for the award of any degree or diploma.

Place: Rourkela

Date:

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ACKNOWLEDGEMENT

It is a great pleasure to express my gratitude and indebtedness to my supervisor prof. **S. K. Acharya** for his guidance, encouragement, moral support and affection through the course of my work.

I am also grateful to Prof. **Sunil Kumar Sarangi**, Director, NIT, Rourkela who took keen interest in the work. My special thanks to Prof. **K.P Maity**, Head of Mechanical Engineering Department and all staff members of the mechanical department for their timely help in completion of this work.

I am also thankful to Mr. **Gujjala Raghavendra,** Mr.**Sudhakar Majhi** and Mrs. **Shakuntala Ojha** of mechanical engineering for their support & help during my experimental work.

This work is also the outcome of the blessing guidance and support of my father and mother Mrs. **Ch saiman joseph** and **ch hebry kumari** this work could have been a distant dream if I did not get the moral encouragement.

I feel pleased and privileged to fulfill my parent's ambition and I am greatly indebted to them for bearing the inconvenience during my M-Tech course. I express my appreciation to my friends for their understanding, patience and active co-operation throughout my M-Tech course finally.

(PRANAYAJOSHI CHANDOLE)

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ABSTRACT

Recently conductive polymer composites obtained by filling polymer matrixes with various Carbon blacks were also reported. Particulate fillers of which carbon black is notable example are widely used as reinforcing fillers in polymer industry. These fillers are added to polymers to achieve desirable and enhance the product service qualities. Commercially available carbon blacks are obtained from thermal cracking of natural gas and furnace black produced by incomplete combustion of oil filled stocks. This carbon black is relatively expensive due to its dependence on dwindling supply of crude oil. It is therefore essential to develop viable alternative source of fillers from renewable resources such as agricultural waste, bamboo stem, oil palm empty fruit bunches and coconut shells which are carbonaceous in nature and rich in organic materials. This biomass can be converted into carbon black thereby reducing unwanted, low value agricultural reduces and underutilized crop into useful, high value materials.

Increase of environmental awareness has led to a growing interest in researching ways of an effective utilization of coconut shell, from which shell is particularly valuable due to its high contains 70% carbon, 1% ash, 30.1% lignin, 19.8% cellulose and 68.7% hemicellulose. It is felt that the value of this agricultural residue can be upgraded by bonding with resin to produce composite suitable for tribological applications.

Keeping this in view the present work has been under taken to develop a polymer matrix composite (epoxy resin) using coconut shell char and to study its tribological behavior, the new hard porous carbon material coconut shell char has been developed by carburizing coconut shell as the main raw material at three different temperature range 600°C and 800^0C. The composite are prepared with different volume fraction of coconut shell Char. Experiments have been conducted under laboratory condition to assess the erosive wear behavior of the developed composite.

Chapter1

INTRODUCTION

Chapter-1

1.1 Background and Motivation

Environmental awareness today motivates the researchers worldwide on the studies of natural fiber reinforced polymer composite and cost effective option to synthetic fiber reinforced composites. The availability of natural fibers and ease of manufacturing have tempted researchers to try locally available inexpensive fibers and to study their feasibility of reinforcement purposes and to what extent they satisfy the required specifications of good reinforced polymer composite for different applications. With low cost and high specific mechanical properties, natural fiber represents a good renewable and biodegradable alternative to the most common synthetic reinforcement, i.e. glass fiber.

The term “natural fiber” covers a broad range of vegetable, animal and mineral fibers. However in the composite industry, it is usually refers to wood fiber and agro based bast, leaf, seed, and stem fibers. These fibers often contribute greatly to the structural performance of plant and, when used in plastic composites, can provide significant reinforcement.

Despite the interest and environmental appeal of natural fibers, there use is limited to non-bearing applications due to their lower strength compared with synthetic fiber reinforced polymer composite. The stiffness and strength shortcomings of bio composites can be overcome by structural configurations and better arrangement in a sense of placing the fibers in specific locations for highest strength performance. Accordingly extensive studies on preparation and properties of polymer matrix composite (PMC) replacing the synthetic fiber with natural fiber like Jute, Sisal, Pineapple, Bamboo, Kenaf and Bagasse were carried out [1-6]. These plant fibers have many advantages over glass fiber or carbon fiber like renewable, environmental friendly, low cost, lightweight, high specific mechanical performance.

High performance synthetic filler materials such as thermoplastic polymers have been employed over the last few decades [7] to serve as filler materials in epoxy resin composites as they have demonstrated superior thermal and toughness stability over the years. However, the last few years have witnessed resurgence in research efforts towards finding environment friendly solutions that would lead to production of more natural filler materials [7]. Natural filler materials can serve as effective alternatives to synthetic filler materials for purposes of reinforcement of polymeric composites. Natural filler materials demonstrate several

advantages. They are biodegradable and non-toxic [8]. They can be treated naturally to acquire strength and rigidity properties similar to their synthetic counterparts. They are an abundant resource, highly available, renewable, and can lead to cost effective production. Some of the disadvantages of natural filler materials are moisture sensitivity, and therefore reduced effectiveness with hydrophobic polymers [9], biological decay, non-uniform filler shapes and sizes, vulnerability to natural environment attacks, and lack of robustness under higher temperatures [10]. However, natural filler materials can be post processed to reduce some of these disadvantages, namely, degradation under moisture and other environment effects [9].

Composite materials are widely used in automotive, construction and packaging application due to their low density, excellent stiffness, and good thermal and mechanical properties. Recent developments on various applications of polymer composites are well documented in many literatures, however the fundamental and applied studies of these materials are still of keen interest to many researchers. Literature survey reveals various attempts made to develop epoxy composites modified with various fillers (such as silica, carbon, carbon black, Al_2O_3, $CaSiO_3$, etc) in order to improve the performance of this matrix. Recently conductive polymer composites obtained by filling polymer matrixes with various Carbon blacks were also reported. Particulate fillers of which carbon black is notable example are widely used as reinforcing fillers in polymer industry. These fillers are added to polymers to achieve desirable and enhance the product service qualities. Commercially available carbon blacks are obtained from thermal cracking of natural gas and furnace black produced by incomplete combustion of oil filled stocks. This carbon black is relatively expensive due to its dependence on dwindling supply of crude oil. It is therefore essential to develop viable alternative source of fillers from renewable resources such as agricultural waste, bamboo stem, oil palm empty fruit bunches and coconut shells which are carbonaceous in nature and rich in organic materials. This biomass can be converted into carbon black thereby reducing unwanted, low value agricultural reduces and underutilized crop into useful, high value materials. Carbon black and activated carbon can be derived from any carbonaceous materials. Biomass waste such as bamboo, coconut shell, cherry stones, sugarcane bagasse, oil palm waste and rice husk are some of the raw materials known to have advantages to replace the commercial man-made carbon [11,12].

Coconut shell particles have high strength and modulus properties along with the added advantage of high lignin content. The high lignin content makes the composites made with these filler more weather resistant and hence more suitable for application as construction materials. Coconut shell flour is also extensively used to make products like furnishing materials, rope etc [13]. The shells also absorb less moisture due to its low cellulose content [13].

In this present work the effectiveness of coconut shell particles (raw fibers) as a source of natural material for reinforcing epoxy resins towards their mechanical, flexural and erosive wear behavior has been studied. The study also involves preparation of composites with epoxy resin as matrices reinforced with coconut shell char produced by physical activation method to be used as reinforcement filler and to study their mechanical, flexural and erosive wear behavior.

1.2 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2: Previous work relevant to the present investigations available in literatures is described in this chapter

Chapter 3: This chapter describes the details of materials required, fabrication techniques and the results from the tests for mechanical properties and erosive wear behavior of the raw coconut shell powder reinforced epoxy composite has been reported.

Chapter 4: In this chapter the coconut shell char produced by physical activation method has been used as reinforcement filler to produce composite material. The improvement in the mechanical and abrasive wear behavior of the composite by the incorporation of char in place of raw coconut shell powder has been reported.

Chapter 5: Conclusions from the above work and recommendations for future work are presented in this chapter

Chapter 2

LITERATURE SURVEY

Chapter-2

2.1 Literature survey:

Literature survey is carried out to get the background information on the issues to be considered in the present research work and to focus the relevance of the present study. The purpose is also to present a thorough understanding of various aspects of carbon black and activated carbon that can be used as reinforcement filler in polymer composite with a special attention to their mechanical properties and abrasive wear behavior.

2.2 Related Work

Products manufactured from carbon are very important in our everyday life. The production of carbon black demand high cost processes and energy consumption. Therefore, an alternative for developing new starting materials for carbon material is needed in order to reduce the cost and fulfill every need of the carbon black consumer. Many researchers have evaluated the by-products of agricultural waste in a new way for the next carbon black generation [14,15].

Carbon black is commercially used as filler and has its own grades and characteristics. The properties of carbon used in the composites mainly depend on the origin, processing conditions and chemical treatments. The particle size, surface activity, degree of interactions with polymer, chemical composition, and degree of irregularity of filler shape was the factors affecting the behaviour of the composites [16].

In India there are many potential natural resources, Most of it comes from the forest and agriculture. Among all natural fibers, Coconut shell particles have high strength and modulus properties along with the added advantage of high lignin content [17]. The high lignin content makes the fiber suitable for manufacturing composites. Coconut shell flour is also extensively used to make products like furnishing materials, rope etc. The shells also absorb less moisture due to its low cellulose content. R.D.T. Filho et al. [17] while studying on the effectiveness of coconut shell particles as a source of natural material for reinforcing epoxy resins towards their flexural properties.

Jain, S et al [18] in their work have chosen bamboo (a biomass waste) as the raw material for preparation of carbon black and activated carbon and used the same as a filler

material in polyester composites. Their results show good mechanical properties, high stiffness and high porosity of the resulted composite.

Flexural and tensile properties of biomass carbon black as filler material in epoxy Composites have been studied by Abdul Khalil et.al. [19]. They performed several Characterization studies on composites prepared from bamboo stems, coconut shells and oil palm fiber bunches. Their results indicate better flexural stability of carbon black reinforced epoxy composites compared to un-reinforced samples. Satya Sai et al. [20] in their work reported that a fluidized bed reactor can more effectively be employed for the production of activated carbon from coconut shell char compared to the conventional processes.

In another paper Abdul Khalil et al[21] produced a composite from carbon black and activated carbon from bamboo with polyester as matrix material. Their results indicates a poor strength in tensile and flexural strength while the tensile and flexural modules shows a reverse phenomenon.

Coconut shells are available in abundance in tropical countries such as Sri Lanka, India, Thailand, Burma, Malaysia, and Indonesia as waste products following consumption of coconut water and meat [22]. Such abundance will be able to meet the gradually increasing demand of filler based composites while reducing natural waste. Procurement and processing of coconut shells to generate coconut char is highly cost effective than most other man made carbon.

Currently, various materials are used to produce activated carbon and some of the most commonly used agricultural wastes such as coconut shell [23], pistachio shell [24], and saw dust [25]. Walnut shell [26] and tropical wood [27]. It is widely agreed [28, 29], that the pore structure and pore size distribution of an activated carbon is largely determined by the nature of the starting material. Pores can be classified into three categories;namely, micropore (<2 nm), mesopore (2–50 nm) and macropore (>50 nm) [30]. These values represent the width, i.e. the distance between the walls for slit-shaped pores or the radius for cylindrical pores. In a comparison between coconut-shell-based activated carbon (CSAC) and wood-based activated carbon, the coconutshell-based activated carbon was shown to have a fine pore distribution with a major portion of its pore volume being represented by pores of radius of less than 1 nm, whereas, wood based activated carbon contained comparatively significant amounts of mesopores and macropores [31]. Hashimoto et al.[32] compared the pores of activated carbon produced from Miike coal of Japan to the activated carbon produced from

coconut shell. They found that the product produced from Miike coal had a bimodal distribution with small amount of micropores and a large amount of macropores, whereas, activated carbon produced from coconut shell had large amount of micropores and a small amount of macropores. A study conducted by Rodriguez-Reinoso and Solano[33,34] on several agricultural wastes like peach stone, cherry stone, apricot stone, palm stone and almond shell found that the botanical family of the material influences the pore size distribution. Besides, the raw material also has been shown to affect the shape of the pore. One of the parameters which, differentiates one material from another is the material composition, i.e.lignin, cellulose and halocellulose. Gergova et al. [35] produced activated carbon from grape seed and cherry stone and attributed the predominatly mesopore and macropore structure of the activated carbon produced from them to the high lignin content in the raw material. The work also revealed the possibility of selecting raw materials to produce activated carbon with certain pore size distribution by recognizing their differences.

After reviewing the existing literature available on coconut shell char reinforced epoxy composite it is found that procurement and processing of coconut shells to generate coconut shell powder and char is highly cost effective than most other natural materials. Coconut particles have high tensile and flexural strength by themselves. Further they can serve as a potential candidate for next generation composite.

Thus the priority of this work is to prepare coconut nut powder and char from coconut shell. These powder and char then will be used as reinforcement material to produce composite and then the mechanical and erosive wear behavior of the composite will be studied.

Chapter 3

MECHANICAL CHARACTERIZATION

Chapter-3

3.1 MATERIALS USED

Materials used in this experimental work are listed below:

1. Epoxy resin
2. Hardener
3. Coconut shell

3.1.1 Epoxy resin

Epoxy resin Araldite LY 556 an unmodified epoxy resin based on Bisphenyl-A supplied by (CIBA GUGYE limited) having the following outstanding properties has been used as the matrix material.

a. Excellent adhesion to different materials.

b. High resistance to chemical and atmospheric attack.

c. High dimensional stability.

d. Free from internal stresses.

e. Excellent mechanical and electrical properties.

f. Odorless, tasteless and completely nontoxic.

g. Negligible shrinkage.

3.1.2 Hardener

Hardener HY951, aliphatic Primary amines which has a viscosity of 10-20 MPa at 25^0 c is used along with the matrix material.

3.1.3 Raw coconut shell powder

The cleaned coconut shells were cut into small pieces by using hammer. These small pieces were then grounded into powder form by a using a jaw crusher and ball milling. The collected powder was then sieved to different mesh sizes. The particle size chosen for the experiments was -90 to +45 microns collected from mesh sizes of between 40 to 70 due to its highest weight percentage among all sizes that shows in the table 3.1. The procedure of making raw coconut shell powder is shown in figure 3.1.

Table 3.1 particle size

Sample No.	Mesh no.	Size range - micron	Size range + micron	Weight Grams approx	Spacing inches	Weight %
1	40	-	420	135	0.0165	27%
2	**70**	**420**	**212**	**183**	**0.0083**	**37%**
3	100	212	150	44	0.0059	9%
4	150	150	104	31	0.0041	6%
5	270	104	53	47	0.0021	9%
6	450	53	32	48	0.0012	10%
7	635	32	20	10	0.0008	2%

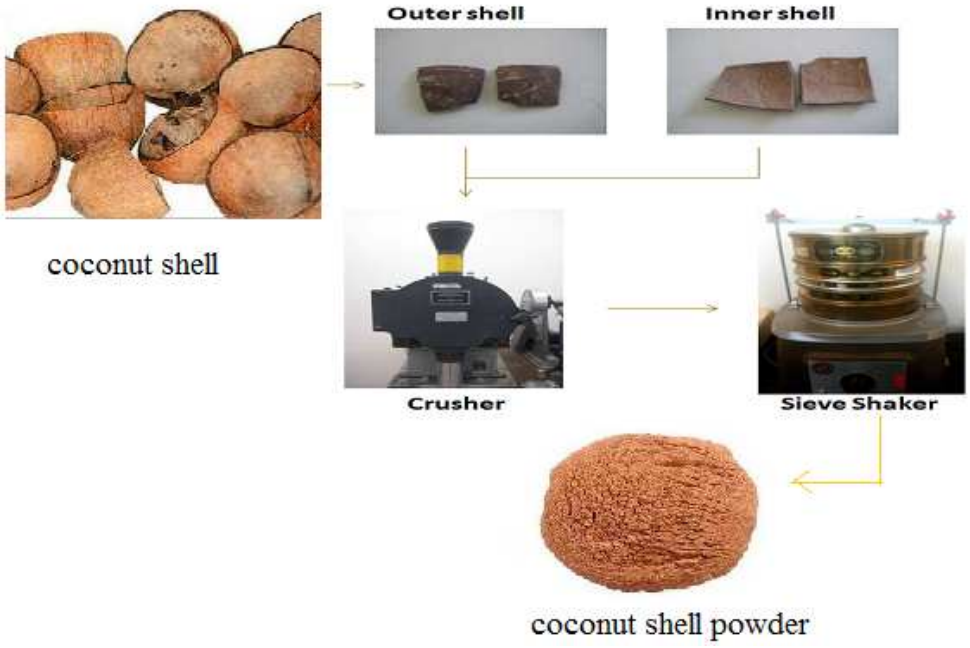

Figure.3.1 procedure of making raw coconut shell powder

3.1.4 Preparation of coconut shell char (600^0 and 800^0C)

The carburization temperature selected was 600˚c, and 800˚c. The required quantities of coconut shell powder were taken in crucibles and were placed in the furnace. It took about three to four hours to reach the required temperature. At this temperature one hour soaking time was allowed. After this 24hrs cooling was allowed so that the furnace comes to room temperature. Then the carburized coconut shell powders were taken out from the furnace for further use. Figure 3.2 shows the procedure of making coconut shell char.

Figure.3.2 procedure of making carburized coconut char.

3.2 PREPARATION OF COMPOSITES:

A wooden mold of 130x100x6 mm Figure-3.3(a) was used for casting the composite sheet. For quick and easy removal of the composite sheet a mold release sheet was put over the glass plate. Mold release spray was also applied at the inner surface of the mold wall after it was set on the glass plate. The weight percents of coconut shell powder and char (ie.5, 10, 20 and 30 wt %), were mixed with the matrix material consisting of epoxy resin and hardener in the ratio of 10:1. Care was taken to avoid formation of air bubbles during pouring. Pressure was then applied from the top and the mold was allowed to cure at room temperature for 72 hrs. During the application of pressure some polymer squeezes out from the mould. For this, care has already been taken during pouring. After 72 hrs the samples were taken out of the mold, after curing the laminate was cut into required size of erosion and other mechanical tests by diamond cutter. In the present case the composites prepared for raw coconut shell and the carbonized char at 600^0C and 800^0C. The density of epoxy resin, coconut shell fiber and char is found respectively. Figure-3.2(b) and(c) shows the photograph of the samples cut from the slab.

Figure- 3.3 (a) Mold (b) Specimen for Tensile test (c) Flexural Test

3.3. CHARACTERIZATION OF THE COMPOSITES

3.3.1 Density

The theoretical density of composite materials in terms of weight fraction is found out from the following equations as given by Agarwal and Broutman [36].

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right)} \tag{3.2}$$

Where '*W*' and 'ρ' represents the weight fraction and density respectively. The suffix *f, m* and *ct* stand for the fiber, matrix and the composite materials. The results are tabulated in Table-3.2.

Table.3.2 Density of different Samples In different conditions

Sample	**Density(gm/cm^3) For Raw Fiber**	**Density(gm/cm^3) For 600^{0}c carbonized char**	**Density(gm/cm^3) For 800^{0}c carbonized char**
5%	0.501	2.04	1.14
10%	0.583	1.186	1.09
20%	0.741	1.248	1.011
30%	1.542	1.049	1.03

3.3.2 Micro-Hardness

Micro-hardness measurement is done using a Lecco Vickers Hardness (LV 700) tester .A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F = 10 N and Vickers hardness number is calculated using the following equation:

$$H_v = \frac{0.1889F}{L^2} \qquad \text{and} \qquad L = \frac{X+Y}{2} \tag{3.3}$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm). The results are tabulated in Table-3.3.

Table.3.3 Hardness of different Samples In different conditions

Sample	**Hardness(Hv) For Raw Fiber**	**Hardness(Hv) For 600^0c carbonized char**	**Hardness(Hv) For 800^0c carbonized char**
5%	189.9	229.4	245.15
10%	197.2	215.7	285.35
20%	195.7	212.7	216.71
30%	178.1	202.9	281.43

3.4 TESTING OF MECHANICAL PROPERTIES OF COMPOSITE

The study of mechanical properties such as tensile strength, flexural strength and hardness of coconut shell fiber reinforced (randomly distributed in the epoxy matrix) composite have been conducted as per ASTM standard.

3.4.1 Tensile Strength

The tensile test is generally performed on flat specimens. The most commonly used specimen geometries are the dog-bone specimen (figure 3.4) and straight-sided specimen with end tabs. The standard test method as per ASTM D 3039-76 has been used; length of the test specimen used is 125 mm. The tensile test is performed in universal testing machine INSTRON H10KS .The test were performed with a cross head speed of 10mm/min.

For each test composite of five samples were tested and average value was taken for analysis.Figure3.5 (a, b) shows the Machine used for the test and the sample in loading condition. The results obtained from the tests of raw and char composites are presented in Table 3.4-3.6

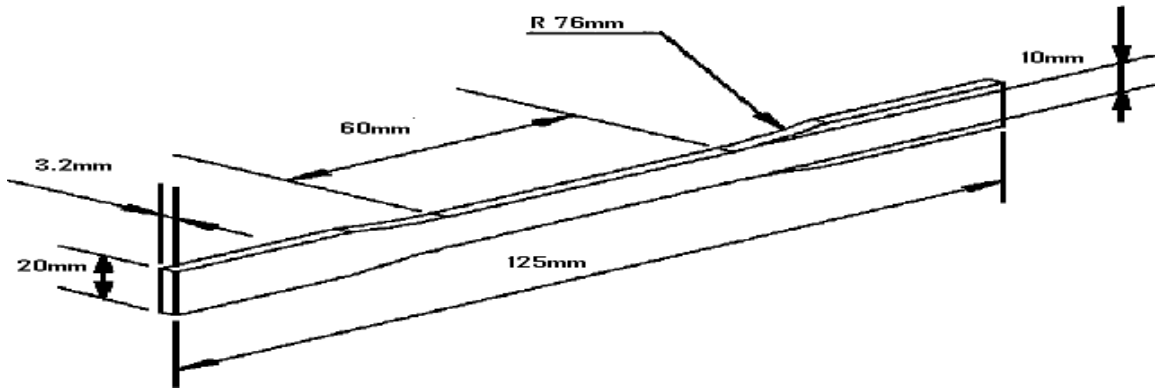

Figure. 3.4 Tensile specimen

(a) **(b)**

Figure. 3.5 INSTRON H10KS TESTING MACHINE

3.4.2 Flexural testing

Flexural test was conducted on the same machine in accordance with ASTM D2344-84. Specimens of 150mm length and 20mm wide were cut and were loaded in three point bending with a recommended span to depth ratio of 16:1 as shown Figure .3.6(a, b). The test was conducted on the same machine used for tensile testing using a load cell of 10kN at 2mm/min rate of loading. The flexural stress in a three point bending test is found out by using equation.

$$\sigma_{max} = \frac{(3P_{max}L)}{(bh^2)} \tag{3.4}$$

Where P_{max} is the maximum load at failure (N), L is the span (mm), b and h is the width and thickness of the specimen (mm), respectively. The flexural modulus is calculated from the slope of the initial portion of the load-deflection curve which is found out by using equation.

$$E = \frac{(mL^3)}{(4bh^3)} \tag{3.5}$$

Where m is the initial slope of the load deflection curve for each stacking sequence, five specimens are tested and average result is obtained. The results obtained from the tests of raw and char composites are presented in Table 3.4-3.6

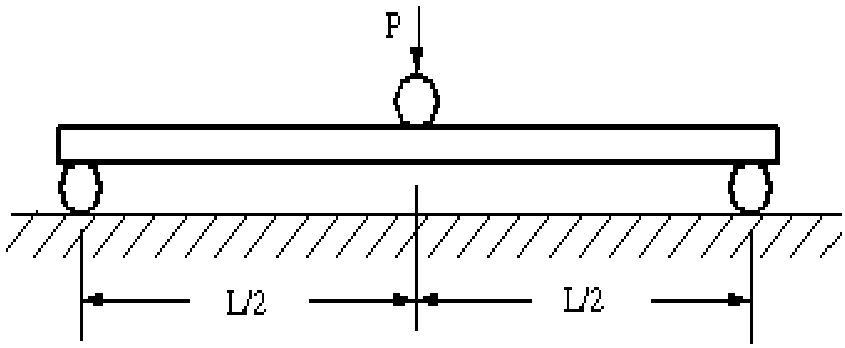

Figure. 3.6(a) Flexural specimen

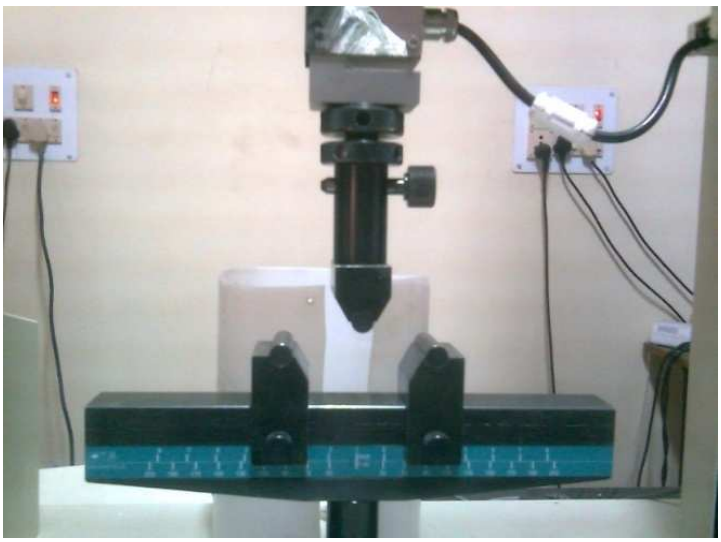

Figure. 3.6(b) Flexural specimen loading position

Table.3.4 Mechanical properties of raw coconut shell powder fiber epoxy composite

Fiber vol %	Flexural Strength (MPa)	Tensile Strength (MPa)
Neat epoxy	17.56	13.50
5	19.35	6.75
10	56.51	23.92
20	53.64	9.35
30	36.68	8.76

Table.3.5 Mechanical properties of carbonized coconut shell char fiber epoxy composite at 600^0c.

Fiber vol %	Flexural Strength (MPa)	Tensile Strength (MPa)
Neat epoxy	17.56	13.50
5	41.82	14.79
10	40.33	16.15
20	56.68	26.63
30	30.74	14.33

Table.3.6 Mechanical properties of carbonized coconut shell char fiber epoxy composite at 800^0c.

Fiber vol %	Flexural Strength (MPa)	Tensile Strength (MPa)
Neat epoxy	17.56	13.50
5	60.64	24.86
10	29.36	19.32
20	30.13	10.38
30	70.26	8.87

3.5 RESULTS AND DISCUSSIONS:

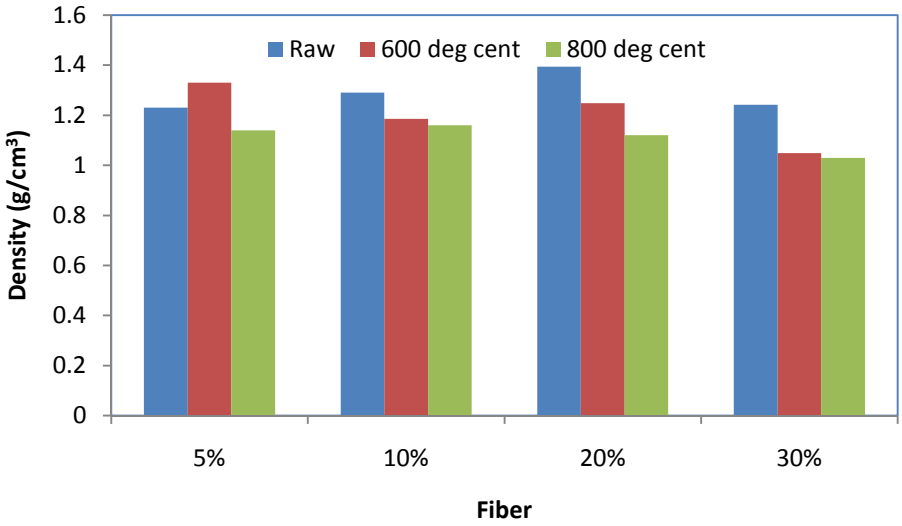

Figure 3.7 Histogram showing the density of all composites at different carburized temperature

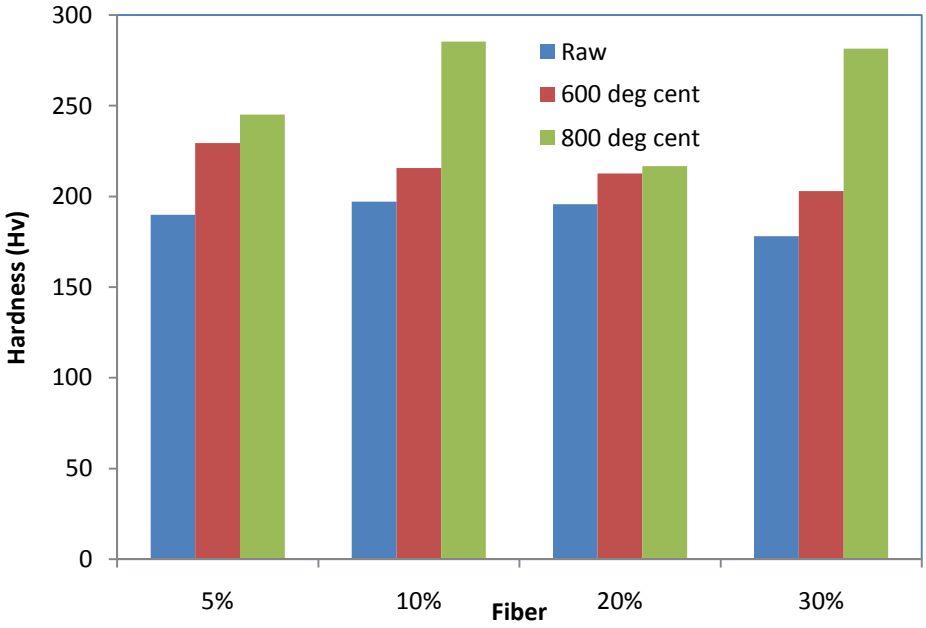

Figure 3.8 Histogram showing the harness of all composites at different carburized temperature

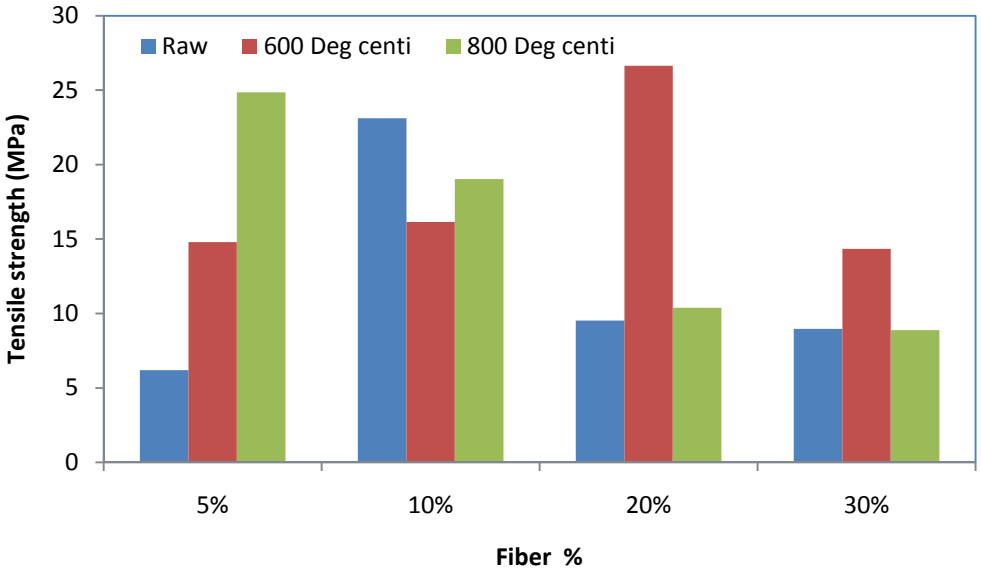

Figure 3.9 Histogram showing the tensile properties of all composites at different carburized temperature

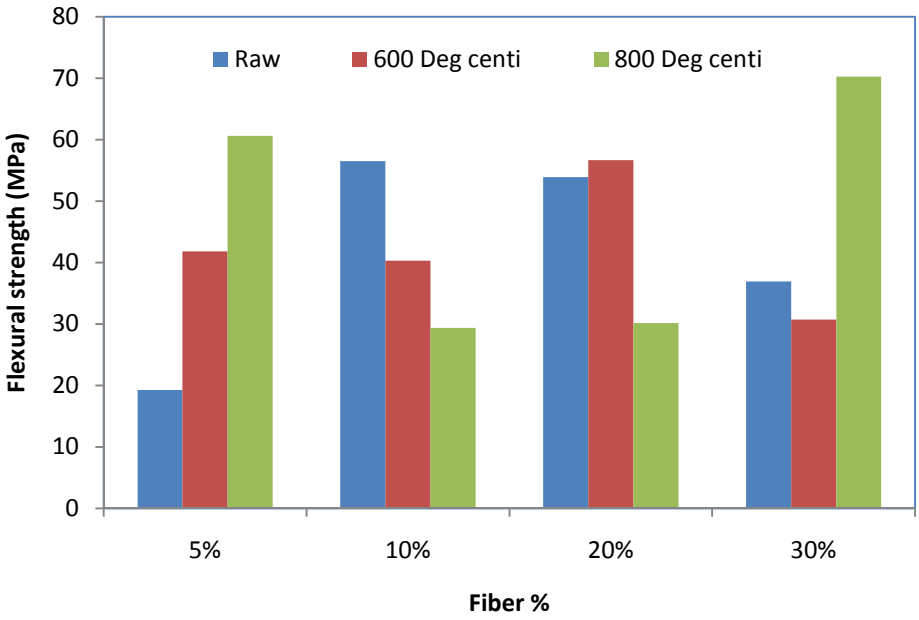

Figure 3.10 Histogram showing the flexural properties of all composites at different carburized temperature

The density test results for various specimens which were prepared with raw coconut and char powder particles with different volume fraction were plotted in figure 3.7. The plot shows that, the density of the composite prepared with char is less when compared to the raw coconut particulate composite. It is also noticed that with increase of fiber concentration the

density goes on increasing and samples with 20% fiber volume fraction of fibers and+ suddenly decreases to some extent because void formation.

Figure 3.8 shows the micro hardness values for different volume fraction of coconut raw and char particulate composite. It is seen that the hardness value is more for char based composites.

The tensile strength results for various specimens which were prepared with raw coconut and char powder particles with different weight fraction were plotted in figure 3.9. The plot shows that, the maximum tensile strength is obtained for the composite prepared with the 20wt % reinforced 600^0C carburized coconut char particulate filled epoxy composite.

Figure 3.10 shows the variation in flexural strength for different volume fraction of particulate composites. The plot shows that, the maximum flexural strength is obtained for the composite prepared with the 30wt % reinforced 800^0C carburized coconut char particulate filled epoxy composite.

Chapter 4

STUDY OF EROSIVE WEAR RATE

Chapter-4

4.1 INTRODUCTION

Solid particle erosion manifests itself in thinning of components, surface roughening, surface degradation, macroscopic scooping appearance and reduction in functional life of the structure. Hence, solid particle erosion has been considered as a serious problem as it is responsible for many failures in engineering applications. Several attempts to understand the basic mechanisms of the erosion were started in the last half of the 20^{th} century and have been continued to the present. In the year of 1995 an article on the past and the future of erosion was presented by Finnie [37]. In this article, the influencing parameters and dominating mechanisms during solid particle erosion were reviewed on the erosion response of metals and ceramic materials. In the same year another article was published by Meng et al. [38] to provide information about the existing wear models and prediction equations.

4.2 DEFINITION

According to Bitter [39], erosion is a material damage caused by the attack of particles entrained in a fluid system impacting the surface at high speed. Hutchings [40] defines it as an abrasive wear process in which the repeated impact of small particles entrained in a moving fluid against a surface result in the removal of material from the surface. Erosion due to the impact of solid particles can either be constructive (material removal desirable) or destructive (material removal undesirable), and therefore, it can be desirable to either minimize or maximize erosion, depending on the application. The constructive applications include sand blasting, high-speed water-jet cutting, blast stripping of paint from aircraft and automobiles, blasting to remove the adhesive flash from bonded parts, erosive drilling of hard materials. Whereas the solid particle erosion is destructive in industrial applications such as erosion of machine parts, surface degradation of steam turbine blades, erosion of pipelines carrying slurries and particle erosion in fluidized bed combustion systems. In most erosion processes, target material removal typically occurs as the result of a large number of impacts of irregular angular particles, usually carried in pressurized fluid streams.

4.3 SOLID PARTICLE EROSION OF POLYMER COMPOSITES

The subject of erosion wear of polymer composite has received substantial attention in the past decades. Interest in this area is commensurate with the increasing utilization of polymer based composites in aerospace, transportation and processing industries, where they can be subjected to multiple solid or liquid particle impact. Examples of such applications are pipe lines carrying sand slurries in petroleum refining, helicopter rotor blades , pump impeller blades, high speed vehicles and aircraft operating in desert environments, radomes, surfing boats where the component encounter impact of lot of abrasives like dust, sand, splinters of materials, slurry of solid particle and consequently the materials undergo erosive wear [41-43].

Many researchers have evaluated the resistance of various types of polymers like nylon, epoxy, polypropylene, bismileimide, etc and their composites to solid particle erosion. Harsha et al. [44] has summarized the work done by some of the investigators on solid particle erosion of polymer composites. Roy et al. while working on erosive wear of polymer composite revealed that the composite materials present a rather poor erosion resistance as compared to metallic materials [45].

The most important factors influencing the erosion rate of the composite materials can be summarized under four categories; (i) The properties of the target materials (matrix material properties and morphology, reinforcement type, amount and orientation, interface properties between the matrices and reinforcements, etc.), (ii) Environment and testing conditions (temperature, chemical interaction of erodent with the target), (iii) Operating parameters (angle of impingement, impinging velocity, particle flux–mass per unit time, etc.) and (iv) The properties of the erodent (size, shape, type, hardness, etc.) [43, 46-48]. Thus it seems that the erosion resistance of the material can be evaluated after investigating the combination of above parameters. In general, erosive behaviour of materials can be grouped into ductile and brittle when erosion rate is evaluated as a function of impact angle. The ductile behaviour is characterized by maximum erosion at low impact angle in the range of 15^0–30°. On the other hand, if maximum erosion occurs at 90°, then the behaviour can be termed as brittle. Reinforced composites have also been some time found to exhibit an intermediate behaviour known as semi-ductile with maximum erosion occurring at an angle in the range of 45^0–60° [49]. However, the above classification is not absolute as the erosion behaviour of a material has a strong dependence on erosion conditions such as impact angle,

impact velocity and erodent properties such as shape, hardness, size etc. In the literature, the erosion behaviour of polymers and its composites has also been characterized by the value of the velocity exponent, '*n*' ($E \alpha v^n$) [41].

Visualizing the importance of polymeric composites, much work has been done to evaluate various types of polymers and their composites to solid particle erosion [47, 50-52]. Most of these workers have carried out a wide range of thermoset and thermoplastic PMCs having glass, carbon, graphite and Kevlar fibers in the form of tape, fabric and chopped mat as reinforcement. However there is no information available on the erosion wear behaviour of coconut shell char reinforced composite. Hence, in this work an attempt has been made to study the erosive wear behaviors of raw coconut shell powder and char reinforced epoxy composite. As an initial investigation in the present work the influence of impinging velocity, impingement angle and fiber loading on erosive wear has been carried out and results of these investigations are presented in the subsequent sections.

4.4 EXPERIMENT

4.4.1 Preparation for the test specimens

The preparation of the test specimens were carried out as per the procedure discussed in chapter-3.Specimens of dimension 30 x 30 x 3.0 mm were cut from the composite slabs. Adequate care has been taken to keep the thickness constant (3mm) for all the samples.

4.4.2 Test apparatus & Experiment

The schematic figure of the erosion test apparatus used for the present investigation designed as per ASTM-G76 standard is shown in Figure-4.1. The rig consists of an air compressor, a particle feeder, and an air particle mixing and accelerating chamber. The compressed dry air is mixed with the erodent particles, which are fed at a constant rate from a conveyor belt-type feeder in to the mixing chamber and then accelerated by passing the mixture through a tungsten carbide converging nozzle of 4 mm diameter. These accelerated particles impact the specimen, and the specimen could be held at various angles with respect to the impacting particles using an adjustable sample holder. The test apparatus has also been fitted with a rotating double disc to measure the velocity of the erodent particle. The impact velocities of the erodent particles has been evaluated experimentally using this rotating double disc method developed as explained by Ives and Ruff [53]. The velocities obtained from this method for various pressures are given in Table-4.1. The conditions under which

the erosion test has been carried out are given in Table 4.2. A standard test procedure is employed for each erosion test. The samples are cleaned in acetone, dried and weighed to an accuracy of 1×10^{-3} gm using an electronic balance, prior and after each test.

Table-4.1 Particle velocity under different air pressure

Sl. No.	Air Pressure (Bar)	Particle velocity (m/s)
1	1	48
2	2	70
3	3	82

The test samples after loading in the test rig were eroded for 1 min. at a given impingement angle and then weighed again to determine weight loss (Δw). The erosion rate (E_r) is then calculated by using the following equation:

$$E_r = \frac{\Delta w}{w_e} \tag{4.1}$$

where Δw is the mass loss of test sample in gm and w_e is the mass of eroding particles (i.e., testing time × particle feed rate). This procedure has been repeated until the erosion rate attains a constant steady-state value. In the present study the same procedure is repeated for 5 times (i.e. expose time was 5min).

The erosion efficiency (η) for the process was obtained by using the equation:

$$\eta = \frac{2E_r H}{\rho \times v^2} \tag{4.2}$$

where 'E_r' is erosion rate (kg/kg), 'H' is hardness of eroding material (Pa) and 'v' is velocity of impact (m/s), proposed by Sundararajan et al. [54]. Experimental results of the erosion test for different volume fraction of raw coconut shell powder and char reinforced epoxy composites with different impingement angle and velocities are tabulated and presented in table 4.3-4.15

Table-4.2 Experimental condition for the erosion test

Test parameters	
Erodent:	Silica sand
Erodent size (μm):	200±50
Erodent shape:	Angular
Hardness of silica particles (HV):	1420±50
Impingement angle (α^0):	30, 45, 60 and 90
Impact velocity (m/s):	48, 70, 82 and 109.
Erodent feed rate (gm/min):	1.467±0.02
Test temperature:	(27 ^{0}C)
Nozzle to sample distance (mm):	10

Figure-4.1 Details of erosion test rig. (1) Sand hopper, (2) Conveyor belt system for sand flow, (3) Pressure transducer, (4) Particle-air mixing chamber, (5) Nozzle, (6) X–Y and h axes assembly, (7) Sample holder.

4.5 RESULT AND DISCUSSION

Based on the tabulated results various graphs were plotted and presented in figure 4.2 to 4.12 for different percentage of reinforcement under different test conditions.

Figures 4.2 – 4.4 illustrate the erosion wear rate of the both neat epoxy and coconut shell raw particulate reinforced epoxy composite as a function of angle of impingement under different impact velocities (v = 48, 70 and 82 m/sec). It is evident from the plot that the erosion rate for the coconut shell raw particulate composite is less when compared to the neat epoxy composites. It is also observed that the peak value (α_{max}) is obtained at 45°. Generally it has been recognized that peak erosion occurs at low impact angle (15°-30°) for ductile materials and at a higher angle (90°) for brittle materials [55]. However if the maximum erosion occurs in the angular range 45^0–60^0, it describes the semi-ductile behaviour of the material [56]. From the experimental results it is clear that coconut shell raw particulate reinforced composites respond to solid particle impact in a purely semi ductile manner since the maximum erosion occurs at 45° impact angle for all the velocity range.

Figures 4.5–4.7 illustrate the erosion wear rate of the both neat epoxy and coconut shell char(600^0C) particulate reinforced epoxy composite as a function of angle of impingement under different impact velocities (v = 48, 70 and 82 m/sec). It is observed that the same trend has followed which has observed in the coconut raw particulate composite so this material also acts as semi ductile material.

Figures 4.8–4.10 illustrate the erosion wear rate of the both neat epoxy and coconut shell char(800^0C) particulate reinforced epoxy composite as a function of angle of impingement under different impact velocities (v = 48, 70 and 82 m/sec). It is evident from the plot that the erosion rate for the composite as well as for pure epoxy increases with the impact angles. It attains a peak value (α_{max}) at 90° and a minimum erosion rate (α_{min}) at 30°. It is clear that coconut char (800^0C) particulate reinforced composites respond to solid particle impact in a purely brittle manner since the maximum erosion occurs at 90° impact angle for all the velocity range.

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It has been reported by Sundararajan *et al* [57, 58] that a term erosion efficiency (η) can be used to describe the nature and erosion mechanism. This parameter indicates the efficiency with which the volume that is displaced by impacting erodent particle is actually removed. They have also reported that ductile material possess very low erosion efficiency (i.e) $\eta <<< 100\%$, where as the brittle material exhibits an erosion efficiency even greater than 100%. The values of erosion efficiencies of composites under study are calculated using equation 4.2 and are listed in table 4.16-4.18 along with their hardness (*H*) and operating conditions. Figure 4.10 and 4.11 shows the variation of erosion efficiency with different impact velocities for 45° and 90° impingement angles. Form table 4.16 it is noticed that the erosion efficiency of coconut raw particulate reinforced epoxy composite varies from 8.37% to 11.83% for different impact velocities studied. Form table 4.17 it is noticed that the erosion efficiency of coconut char 600^0C particulate reinforced epoxy composite varies from 1.68% to 9.60% for different impact velocities studied. Form table 4.18 it is noticed that the erosion efficiency of coconut char 800^0C particulate reinforced epoxy composite varies from 3.06% to 28.37% for different impact velocities studied.

4.6 SURFACE MORPHOLOGY

To characterize the morphology of eroded surfaces and the mode of material removal, the eroded samples are observed under a scanning electron microscope (SEM). Figure 4.13 (a) shows the micrographs of the 5 vol % of coconut raw partiulcte reinforced epoxy composite eroded at 45°. It clearly indicates the erosion of both epoxy and fibers. No crack are visible on the surface..

Figure 4.13 (b) shows the micrographs of the 10 vol % of coconut raw partiulcte reinforced epoxy composite eroded at 45°. It clearly shows the groove formation and subsequent erosion by formation of a channel. Both matrix and fibers eroded simultaneously.

Figure 4.13 (c) shows the micrographs of the 20 vol % of coconut raw partiulcte reinforced epoxy composite eroded at 45°. It clearly shows the formation of number of

grooves and cracking of matrix material. The matrix material probebely is not capable of holding the fiber in place. Therefore the erosion is higher.

4.7 CONCLUSIONS

Based on the study of the erosive wear behavior of coconut raw and char particulate composites at various impingement angles, impact velocities for different fiber volume fraction with silica sand as erodent the following conclusions are drawn.

- The composite prepared with raw coconut particles and char 600^0C exhibited a maximum erosion rate at an impingement angle of 45° under present experimental condition indicating semi ductile behavior.
- The composite prepared with char 800^0C exhibited a maximum erosion rate at an impingement angle of 90° under present experimental condition indicating brittle behavior.

- Fiber volume fraction and velocity of impact has a significant influence on the erosion rate of the composite.

- The erosion efficiency values obtained experimentally also indicate that the composite behaves in a semi ductile erosion response.

Table-4.3 Weight loss and Erosion rate of Neat epoxy composites with respect to impingement angle due to erosion for a period of 5 min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0045	0.7865
	45^0	0.0062	1.0485
	60^0	0.0085	1.4855
	90^0	0.0144	2.4472
70	30^0	0.0052	0.8735
	45^0	0.0073	1.2235
	60^0	0.0095	1.6605
	90^0	0.0135	2.3595
82	30^0	0.0087	1.3985
	45^0	0.0115	2.0145
	60^0	0.0155	2.7095
	90^0	0.0260	4.5445

Table-4.4 Weight loss and Erosion rate of 5% raw coconut shell powder epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0267	0.0002
	45^0	0.0341	0.0003
	60^0	0.0236	0.0002
	90^0	0.0243	0.0002
70	30^0	0.0550	0.0005
	45^0	0.0714	0.0006
	60^0	0.0644	0.0006
	90^0	0.0502	0.000
82	30^0	0.0145	0.0006
	45^0	0.0221	0.0010
	60^0	0.0175	0.0008
	90^0	0.0146	0.0006

Table-4.5 Weight loss and Erosion rate of 10% raw coconut shell powder epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0302	0.0007
	45^0	0.0354	0.0003
	60^0	0.0315	0.0002
	90^0	0.0253	0.0002
70	30^0	0.0609	0.0005
	45^0	0.0766	0.0007
	60^0	0.0701	0.0006
	90^0	0.0555	0.0005
82	30^0	0.0875	0.0008
	45^0	0.1176	0.0011
	60^0	0.0983	0.0009
	90^0	0.0765	0.0006

Table-4.6 Weight loss and Erosion rate of 20% raw coconut shell powder epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0342	0.0003
	45^0	0.0400	0.0003
	60^0	0.0331	0.0003
	90^0	0.0296	0.0002
70	30^0	0.0732	0.0006
	45^0	0.0995	0.0009
	60^0	0.0888	0.0008
	90^0	0.0764	0.0007
82	30^0	0.1060	0.0010
	45^0	0.1391	0.0013
	60^0	0.1250	0.0011
	90^0	0.1005	0.0009

Table-4.7 Weight loss and Erosion rate of 30% raw coconut shell powder epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0390	0.0003
	45^0	0.0469	0.0004
	60^0	0.0389	0.0003
	90^0	0.0355	0.0003
70	30^0	0.0807	0.0006
	45^0	0.1185	0.0011
	60^0	0.1010	0.0009
	90^0	0.0943	0.0008
82	30^0	0.1213	0.0011
	45^0	0.1589	0.0015
	60^0	0.1402	0.0013
	90^0	0.1098	0.0010

Table-4.8 Weight loss and Erosion rate of 5% carbonized coconut char at 600^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

elocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0400	0.0003
	45^0	0.0492	0.0004
	60^0	0.0415	0.0003
	90^0	0.0444	0.0004
70	30^0	0.0528	0.0005
	45^0	0.0849	0.0008
	60^0	0.0688	0.0006
	90^0	0.0855	0.0008
82	30^0	0.0525	0.0005
	45^0	0.1108	0.0010
	60^0	0.0792	0.0007
	90^0	0.0998	0.0009

Table-4.9 Weight loss and Erosion rate of 10% carbonized coconut char at 600^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0324	0.0003
	45^0	0.0438	0.0004
	60^0	0.0394	0.0003
	90^0	0.0422	0.0004
70	30^0	0.0365	0.0003
	45^0	0.0648	0.0006
	60^0	0.0515	0.0004
	90^0	0.0695	0.0006
82	30^0	0.0370	0.0003
	45^0	0.0881	0.0008
	60^0	0.0509	0.0004
	90^0	0.0766	0.0007

Table-4.10 Weight loss and Erosion rate of 20% carbonized coconut char at 600^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0427	0.0004
	45^0	0.0518	0.0002
	60^0	0.0460	0.0004
	90^0	0.0482	0.0003
70	30^0	0.0638	0.0006
	45^0	0.1066	0.0012
	60^0	0.0839	0.0007
	90^0	0.091	0.0008
82	30^0	0.0676	0.0006
	45^0	0.1306	0.0012
	60^0	0.1030	0.0009
	90^0	0.1196	0.0011

Table-4.11 Weight loss and Erosion rate of 30% carbonized coconut char at 600^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0461	0.0004
	45^0	0.0531	0.0005
	60^0	0.0488	0.0004
	90^0	0.0567	0.0005
70	30^0	0.0755	0.0007
	45^0	0.1176	0.0011
	60^0	0.1072	0.0012
	90^0	0.1281	0.0013
82	30^0	0.0886	0.0008
	45^0	0.1512	0.0014
	60^0	0.1296	0.0012
	90^0	0.1405	0.0013

Table-4.12 Weight loss and Erosion rate of 5% carbonized coconut char at 800^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss '∆w' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0387	0.0003
	45^0	0.0481	0.0004
	60^0	0.0676	0.0006
	90^0	0.0850	0.0008
70	30^0	0.0496	0.0004
	45^0	0.0639	0.0006
	60^0	0.0821	0.0007
	90^0	0.0962	0.0009
82	30^0	0.1012	0.0009
	45^0	0.1341	0.0012
	60^0	0.1335	0.0012
	90^0	0.1540	0.0014

Table-4.13 Weight loss and Erosion rate of 10% carbonized coconut char at 800^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0271	0.0002
	45^0	0.0351	0.0003
	60^0	0.0479	0.0004
	90^0	0.0637	0.0006
70	30^0	0.0301	0.0002
	45^0	0.0454	0.0001
	60^0	0.0636	0.0006
	90^0	0.0754	0.0007
82	30^0	0.0855	0.0008
	45^0	0.1153	0.0010
	60^0	0.1224	0.0011
	90^0	0.1443	0.0013

Table-4.14 Weight loss and Erosion rate of 20% carbonized coconut char at 800^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0524	0.0004
	45^0	0.0694	0.0006
	60^0	0.0739	0.0007
	90^0	0.1137	0.0010
70	30^0	0.0549	0.0005
	45^0	0.0923	0.0008
	60^0	0.1144	0.0010
	90^0	0.1255	0.0011
82	30^0	0.1077	0.0010
	45^0	0.1540	0.0014
	60^0	0.1876	0.0017
	90^0	0.2050	0.0016

Table-4.15 Weight loss and Erosion rate of 30% carbonized coconut char at 800^0C epoxy composites with respect to impingement angle due to erosion for a period of 5min

Velocity (m/s)	Impact Angle (°)	Weight loss 'Δw' (gm)	Erosion Rate (gm/gm)
48	30^0	0.0616	0.0005
	45^0	0.0798	0.0007
	60^0	0.0916	0.0008
	90^0	0.1260	0.0011
70	30^0	0.0656	0.0006
	45^0	0.1089	0.0010
	60^0	0.1239	0.0011
	90^0	0.1466	0.0013
82	30^0	0.1230	0.0011
	45^0	0.1817	0.0017
	60^0	0.21638	0.0020
	90^0	0.2610	0.0024

Table-4.16 Erosion efficiency (η) of various composite samples for raw coconut shell powder.

Impact Velocity 'v' (m/s)	Impact angle 'α'	Erosion efficiency (η)				
		Neat Epoxy	5%raw	10%raw	20%raw	30%raw
		H=175.5 (Pa)	H=189.9 (Pa)	H=197.4 (Pa)	H=195.7 (Pa)	H=178.1 (Pa)
48	30^0	2.32	8.34	8.43	7.44	3.71
	45^0	3.14	10.64	9.87	8.71	4.46
	60^0	3.53	7.36	8.64	7.20	3.70
	90^0	3.83	7.60	7.05	6.45	3.37
70	30^0	1.88	8.07	7.98	7.47	3.61
	45^0	2.52	10.48	9.97	10.21	5.29
	60^0	3.26	9.45	9.19	9.09	4.52
	90^0	3.61	7.37	7.32	7.82	4.21
82	30^0	1.32	7.77	8.33	7.90	3.95
	45^0	2.38	11.83	11.23	10.37	5.18
	60^0	2.87	9.36	9.39	9.32	4.57
	90^0	3.80	7.84	7.31	7.49	3.57

Table-4.17 Erosion efficiency (η) of various composite samples for 600^0C carbonized coconut shell char.

Impact Velocity 'v' (m/s)	Impact angle 'α'	Erosion efficiency (η)				
		Neat Epoxy	5% 600^0C	10% 600^0C	20% 600^0C	30% 600^0C
		H=175.5 (Pa)	H=229.4 (Pa)	H=215.7 (Pa)	H=212.7 (Pa)	H=202.9 (Pa)
48	30^0	2.32	3.70	4.86	6.00	7.33
	45^0	3.14	4.56	6.57	7.28	8.46
	60^0	3.53	3.85	5.90	6.46	7.78
	90^0	3.83	4.11	6.32	6.75	9.04
70	30^0	1.88	2.30	2.58	4.21	5.66
	45^0	2.52	3.70	4.56	7.04	8.81
	60^0	3.26	3.04	3.63	5.49	8.03
	90^0	3.61	3.77	4.89	6.04	9.60
82	30^0	1.32	1.68	1.90	3.25	4.85
	45^0	2.38	3.51	4.52	6.28	8.25
	60^0	2.87	2.51	2.61	4.95	7.07
	90^0	3.80	3.16	3.93	5.75	7.67

Table-4.18 Erosion efficiency (η) of various composite samples for 800^{0}C carbonized coconut shell char.

Impact Velocity 'v' (m/s)	Impact angle 'α'	Erosion efficiency (η)				
		Neat Epoxy	5% 800^{0}C	10% 800^{0}C	20% 800^{0}C	30% 800^{0}C
		H=175.5 (Pa)	H=245.1 (Pa)	H=285.3 (Pa)	H=216.7 (Pa)	H=281.4 (Pa)
48	30^0	2.32	6.85	5.84	9.26	13.86
	45^0	3.14	8.53	7.54	12.26	17.95
	60^0	3.53	11.89	10.33	13.05	20.61
	90^0	3.83	15.06	13.74	20.08	28.37
70	30^0	1.88	4.11	3.06	4.56	6.87
	45^0	2.52	5.32	4.60	7.66	11.52
	60^0	3.26	6.83	6.45	9.50	13.11
	90^0	3.61	8.04	7.60	10.37	14.81
82	30^0	1.32	6.16	6.32	6.51	9.48
	45^0	2.38	8.13	8.52	9.31	14.01
	60^0	2.87	8.10	9.04	11.31	16.68
	90^0	3.80	9.35	10.66	12.40	20.13

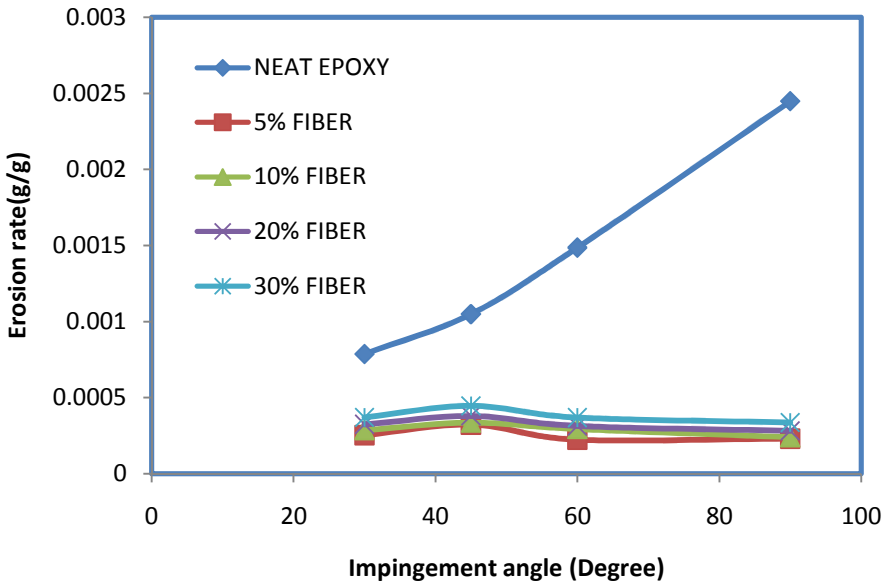


Figure.4.2 Variation of erosion rate with impingement angle of various raw coconut shell powder epoxy composite at impact velocity of 48 m/s

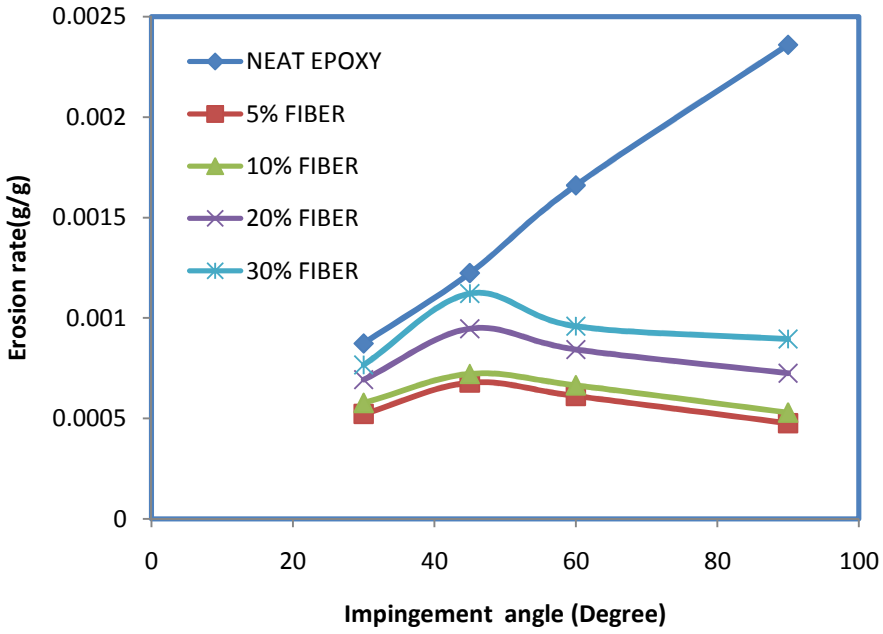


Figure.4.3 Variation of erosion rate with impingement angle of various raw coconut shell powder epoxy composite at impact velocity of 70 m/s

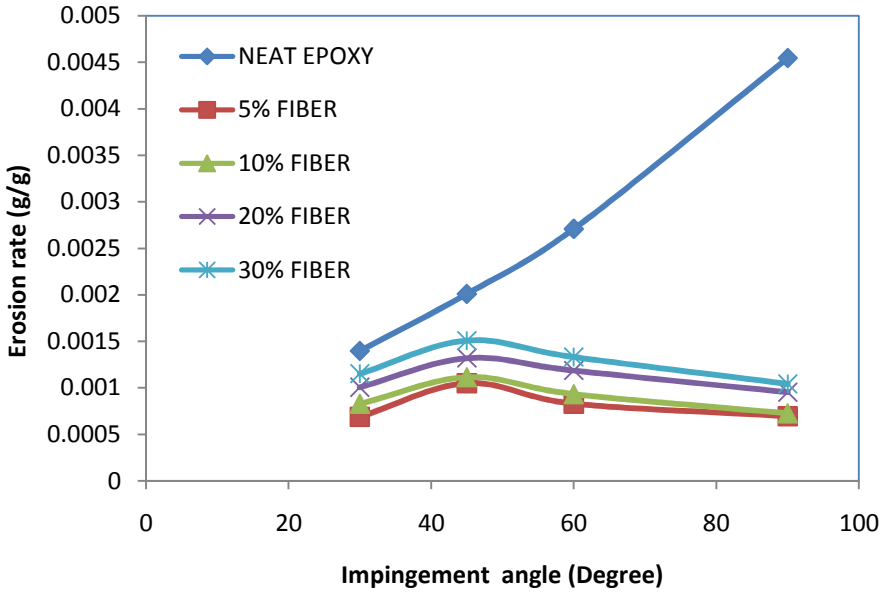


Figure.4.4 Variation of erosion rate with impingement angle of various raw coconut shell powder epoxy composite at impact velocity of 82 m/s

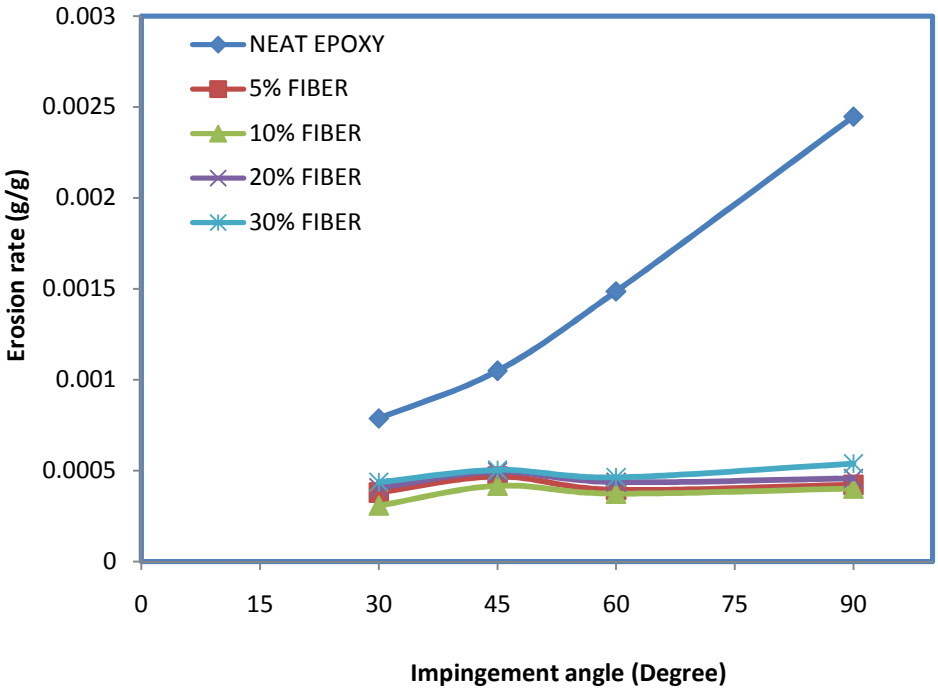


Figure.4.5 Variation of erosion rate with impingement angle of various at 600^{0}C carburized coconut shell char epoxy composite at impact velocity of 48 m/s

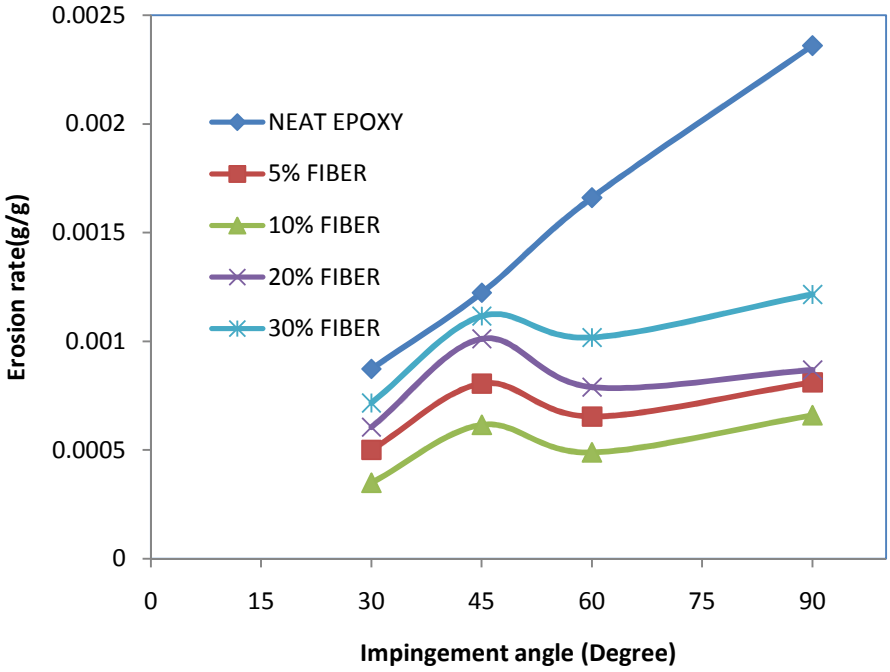


Figure.4.6 Variation of erosion rate with impingement angle of various at 600^{0}C carburized coconut shell char epoxy composite at impact velocity of 70 m/s

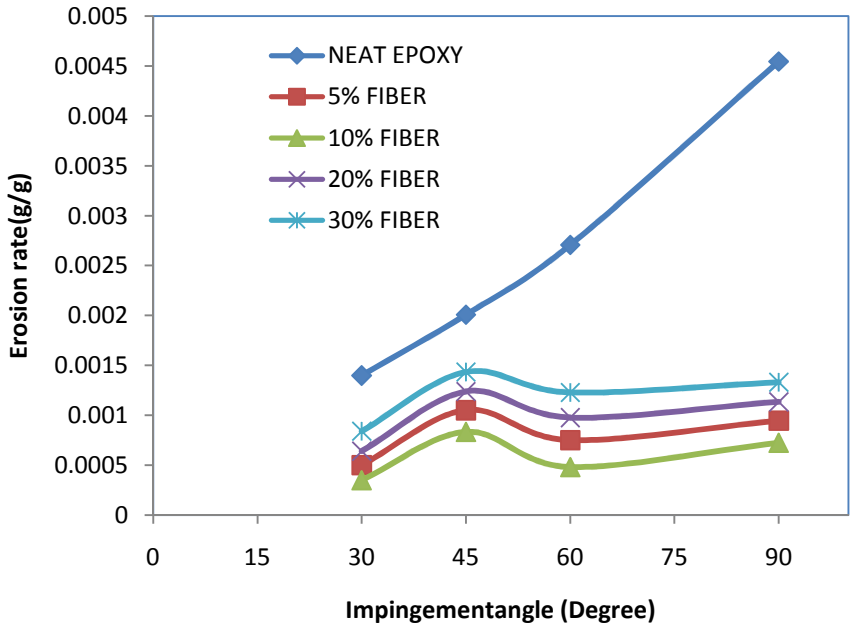


Figure.4.7 Variation of erosion rate with impingement angle of various at 600^{0}C carburized coconut shell char epoxy composite at impact velocity of 82 m/s

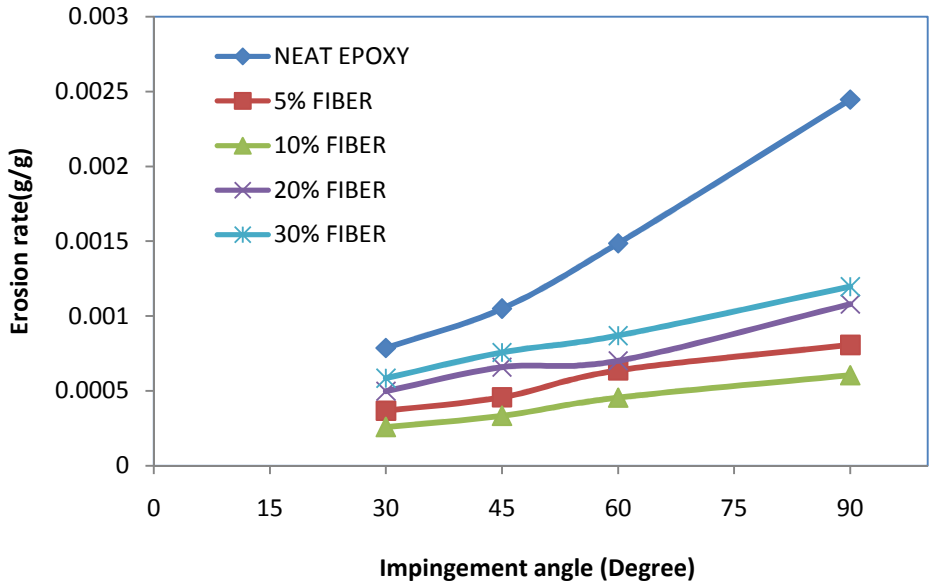


Figure.4.8 Variation of erosion rate with impingement angle of various at 800^{0}C carburized coconut shell char epoxy composite at impact velocity of 48 m/s

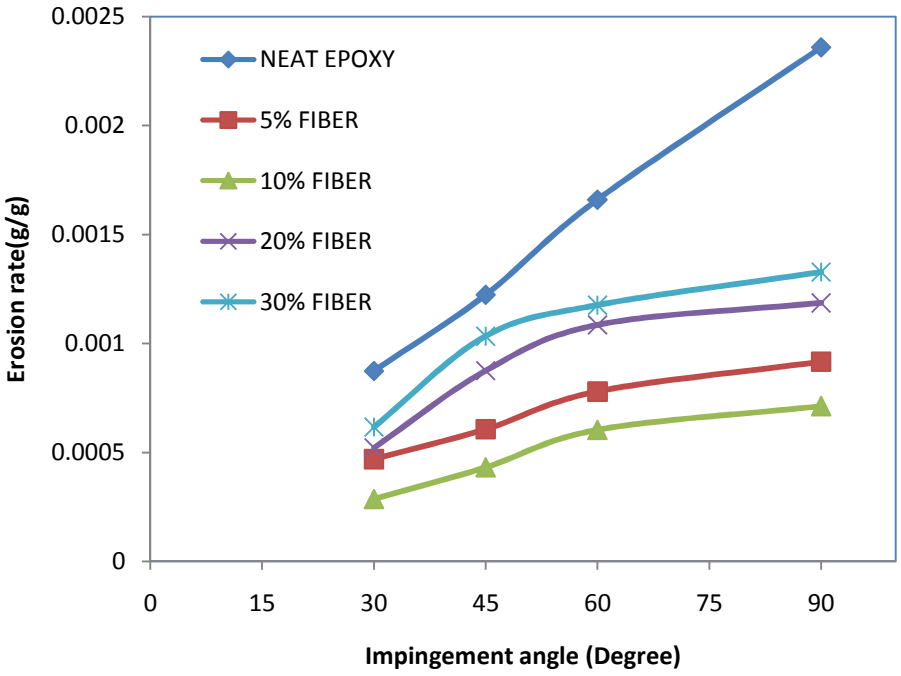


Figure.4.9 Variation of erosion rate with impingement angle of various at 800^{0}C carburized coconut shell char epoxy composite at impact velocity of 70 m/s

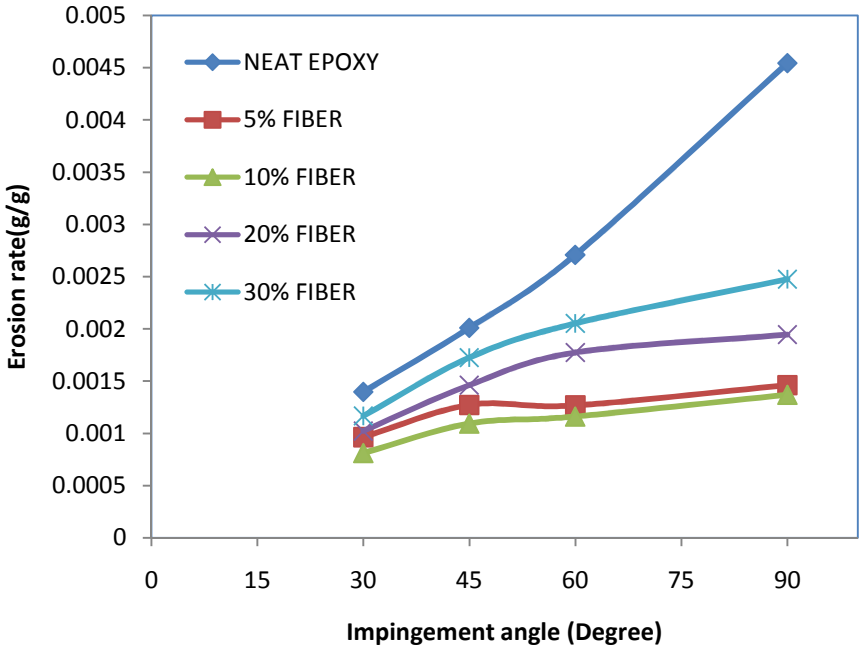


Figure.4.10 Variation of erosion rate with impingement angle of various at 800^{0}C carburized coconut shell char epoxy composite at impact velocity of 82 m/s

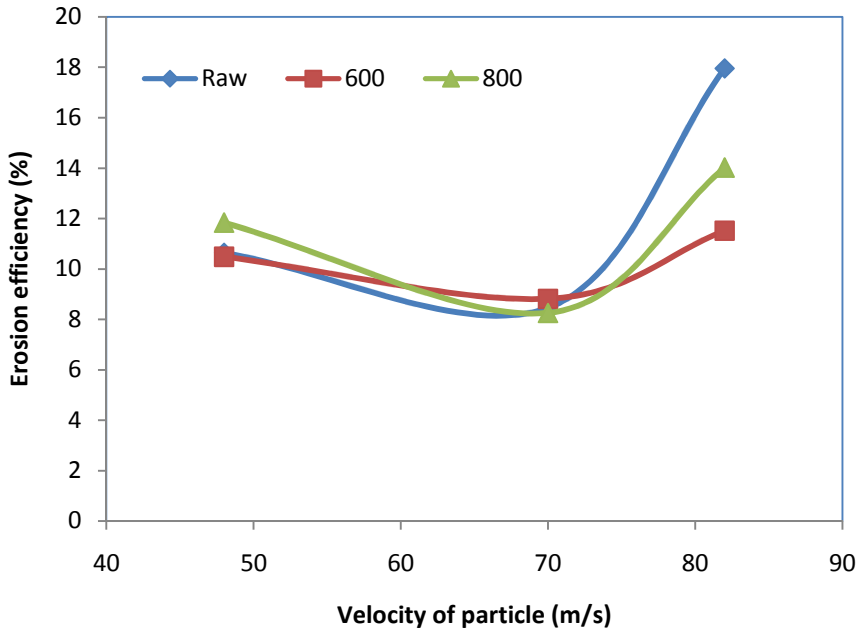


Figure.4.11 Variation of erosion efficiency with velocity of particle at Impingement angle 45^0

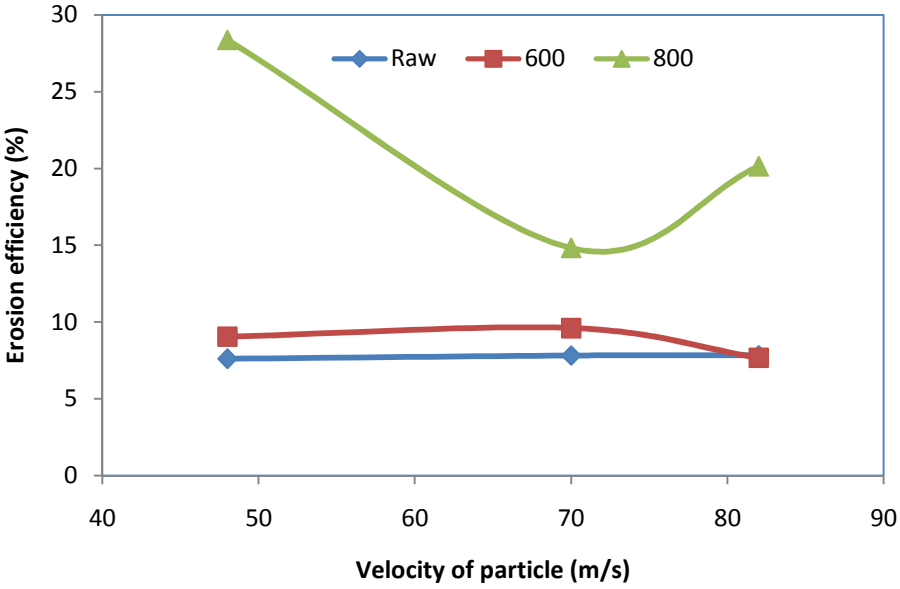
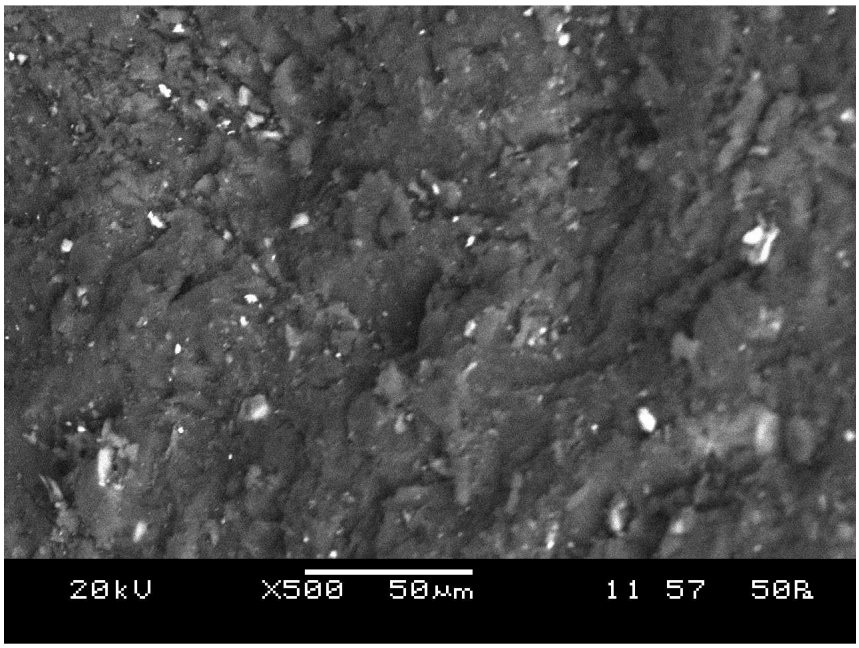
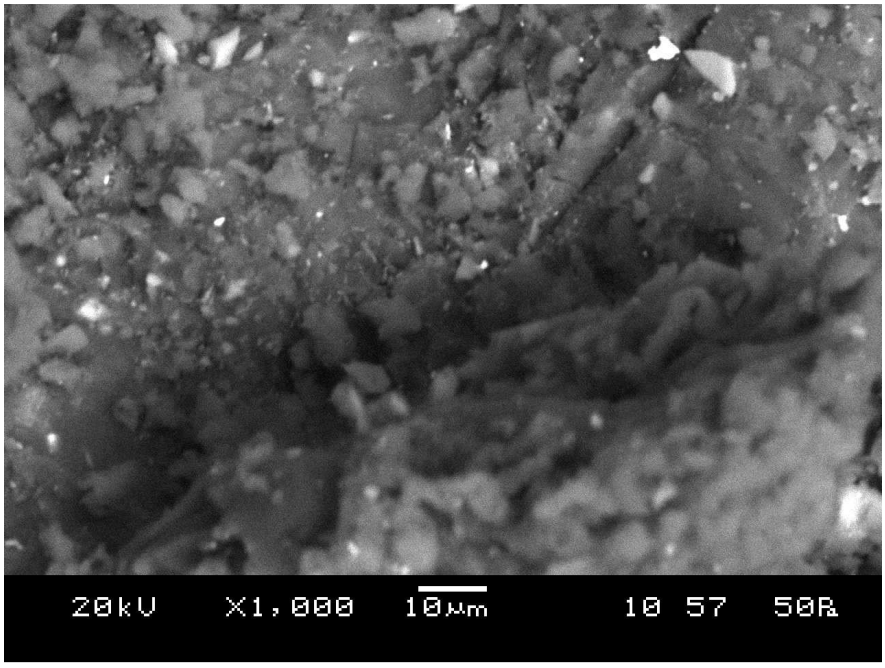


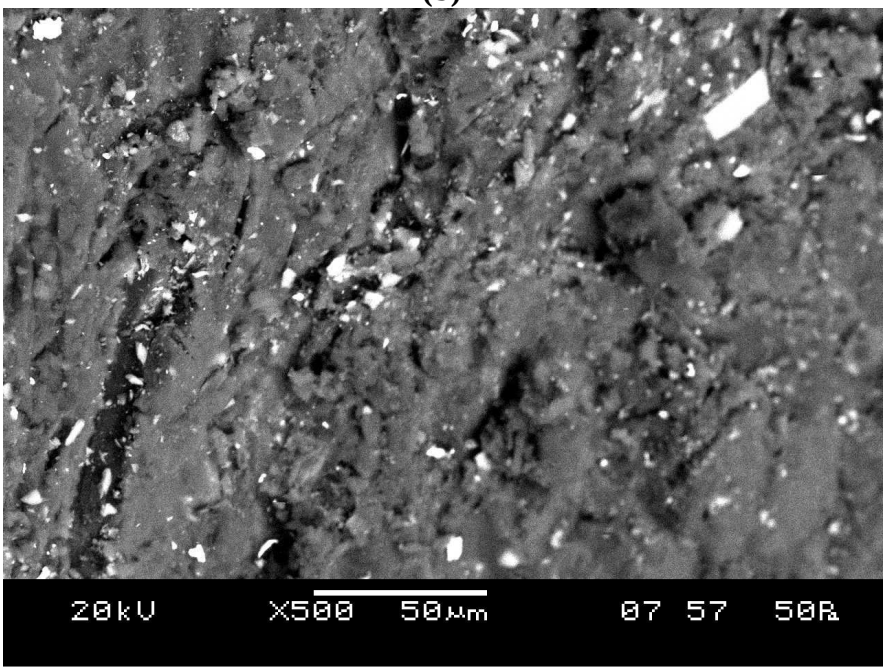
Figure.4.12 Variation of erosion efficiency with velocity of particle at Impingement angle 90^0



(a)



(b)



(c)

Figure-4.13 SEM micrograph of surfaces eroded at 45° of different volume percentage composite, (a) 5% (b) 10 and (c) 20%

Chapter 5

CONCLUSIONS

Chapter 5

CONCLUSIONS:

- The density of the composite prepared with char is less when compared to the raw coconut particulate composite. It is also noticed that with increase of fiber concentration the density goes on increasing and samples with 20% fiber volume fraction of fibers and suddenly decreases to some extent because void formation.

- The micro hardness values for different volume fraction of coconut raw and char particulate composite. It is seen that the hardness value is more for char based composites.

- The maximum tensile strength is obtained for the composite prepared with the 20wt % reinforced 600^0C carburized coconut char particulate filled epoxy composite.

- The maximum flexural strength is obtained for the composite prepared with the 30wt % reinforced 800^0C carburized coconut char particulate filled epoxy composite.

- As for an the erosion wear resistance is concerned coconut shell char reinforced epoxy composite shows semi ductile behavior at 600^0 C carburization temperature. When the temperature changes to 800^0C the behavior changes to brittle nature.

- The erosion efficiency values obtained experimentally also indicate that the composite behaves in a semi ductile erosion response.

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Publications:-

1. Pranaya Joshi C, S.K.Acharya, Gujjala Raghavendra **''Tribo Potential of Coconut Shell Reinforced Epoxy Composites''** International Journal of Engineering, Science and Technology ,Under review

2. Pranaya Joshi C, Dillip Kumar Sahoo, S.K.Acharya, Gujjala Raghavendra, "**Erosive Wear Behaviour of Orange Peel Fiber Reinforced Epoxy Composite**", presented at "International conference on Futuristic Trends in Materials and Energy Systems (FTME-2011)" at VR Siddhartha Engg. College, Vijayawada on 29-30th December 2011